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This is a request for filing a PROVISIONAL APPLICATION FOR PATENT under 37 CFR 1.53(c).

Express Mail Label No.

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Additional inventors are being named on the ______ *separately numbered sheets attached hereto*

TITLE OF THE INVENTION (500 characters max)

Methods and Apparatus for Multi-Carrier Communication Systems with Adaptive Transmission and Feedback

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ENCLOSED APPLICATION PARTS *(check all that apply)*

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☐ Application Data Sheet. See 37 CFR 1.76

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☐ Other (specify) ______

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☒ Applicant claims small entity status. See 37 CFR 1.27.

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Methods and Apparatus for Multi-Carrier Communication Systems with Adaptive Transmission and Feedback

1 Background of the Invention

Adaptive modulation and coding (AMC) has been used in wireless systems to improve spectral efficiency in a fading environment where signal quality varies significantly. By adjusting the modulation and coding scheme (MCS) in accordance with the varying signal-to-noise-plus-interference ratio (SINR), reliable communication link can be maintained between communicating devices. For example, in CDMA2000 1xEV-DO system, twelve different modulation/coding schemes are provided. AMC is also used in CDMA2000 1xEV-DV and 3GPP HSDPA systems.

In addition to MCS, other system functionalities, such as channel estimation, transmission power control (TPC), subchannel configuration, can be adjusted in accordance with state of the communication channel to improve performance. For example, channel estimation is usually carried out using so called training symbols or pilot data, which are known to both the transmitter and the receiver. For coherent modulation, the channel information can be extracted at the receiver by comparing the pilots and their corresponding received versions. For non-coherent modulation, the received samples of those pilots are used as reference for the detection of the transmitted data. Channel estimation is an important part of multi-carrier communication systems such as Orthogonal Frequency Division Multiplexing (OFDM) systems. For example, in conventional OFDM systems, such as IEEE802.11a, 802.11g, 802.16, or DVB-T system, pilots are transmitted for the channel estimation purpose. However, the number of pilots and pilot patterns are fixed, independent of other functionalities such as MCS, TPC, subchannel configuration.

Fast TPC can be used to compensate for fast fading. In a multi-cell multiple access system, TPC is also used to reduce intra-cell and inter-cell interference and conserver battery life for the mobile station by not transmitting excessive power when not needed. However, TPC is usually considered an independent function in a wireless system in that it is not related to MCA, pilot attributes, or subchannel configuration.

Subchannel configuration is normally defined and fixed in the operation. It is usually not considered as adjustable functionality of the system to adapt to user profile and/or operational environment.

2 Summary of the Invention

This invention describes the methods and apparatus to carry out adaptative transmission where modulation schemes, coding rates, training pilot patterns, TPC levels, and subchannel configurations are jointly adjusted to adapt to the channel

conditions in order to maximize the overall system capacity and spectral efficiency without wasting radio resource and compromising error probability performance. Furthermore, the subchannel composition is designed to be configurable so that it can be adjusted statically or dynamically according to user profiles or environment conditions. The methods for obtaining the channel information and for transmitting the control information in the joint adaptation scheme are also included in the present invention, and methods for reducing the overhead of messaging such as feedback of channel condition and indexing of the joint scheme are described.

The multi-carrier system mentioned in this invention can be of any special formats such as OFDM, or Multi-Carrier Code Division Multiple Access (MC-CDMA). The invention can be applied to downlink, uplink, or both, where the duplexing technique can be either Time Division Duplexing (TDD) or Frequency Division Duplexing (FDD).

3 Brief Description of the Drawings

The present invention will be thoroughly understood from the detailed description given below and from the accompanying drawings of various embodiments of the invention, which, however, should not be taken to limit the invention to the specific embodiments, but are for explanation and understanding only.

Figure 1: A representative cellular communication system: Base Station 1 is communicating with Mobile Station 1 and Mobil Station 2 in Sector A of its cell site, and Base Station 2 is communicating with Mobile Stations 3, 4, and 5 in Sector B of its cell site.

Figure 2: The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Data subcarriers can be grouped into subchannels in a particular way. The pilot subcarriers are also distributed over the entire channel in a particular way.

Figure 3: The radio resource is divided into small units in both the frequency and time domains: subchannels and time slots. The basic structure of a multi-carrier signal in the time domain is made up of time slots.

Figure 4 is an illustration of the control process between Device A and Device B. Device A transmits the data and the associated control information to Device B after the adaptation process. Device B measures the channel condition and feeds the CQI information back to Device A.

Figure 5 illustrates the joint adaptation process at the transmitter of an OFDM system which controls the coding, modulation, training pilot pattern, and transmission power for a subchannel.

Figure 6 is an illustration of the control messaging associated with the data transmission between the communication devices: AMCTP indicator associated with the data transmission on the forward link from the transmitter to the receiver, and CQI feedback on the return channel from the receiver to the transmitter.

Figure 7: Two different training pilot patterns are plotted for a multi-carrier system where the dark shaded time-frequency grids are allocated as training pilot symbols.

Figure 8 illustrates the power control in AMCTP scheme for an OFDM system where digital variable gains G_1, G_2, ..., and G_N are applied to the subchannels in digital domain and the variable gain of G_a in analog domain is used to control the total transmission power to meet the requirement for the transmission power of the device.

4 Detailed Description

The present invention is applicable to a communication system with multiple transmitters and multiple receivers. Such a system is shown in Figure 1 where Base Station 1 is communicating with Mobile Station 1 and Mobile Station 2 in Sector A of its cell site while Base Station 2 is communicating with Mobile Stations 3, 4, and 5 in Sector B of its cell site. Multi-carrier multiple access system is a special case of general communication systems which we use as a representative hereafter to describe the invention.

4.1 Multi-Carrier Communication System

The physical media resource (e.g., radio or cable) in a multi-carrier communication system can be divided in both the frequency and time domains. This canonical division provides a high flexibility and fine granularity for resource sharing.

The basic structure of a multi-carrier signal in the frequency domain is made up of subcarriers. Within a particular spectral band or channel, there are a fixed number of subcarriers. There are three types of subcarriers:

1. Data subcarriers, which carries information data;
2. Pilot subcarriers, whose phases and amplitudes are predetermined and made known to all receivers and which are used for assisting system functions such as estimation of system parameters; and
3. Silent subcarriers, which have no energy and are used for guard bands and DC carrier.

The data subcarriers can be arranged into groups called subchannels to support scalability and multiple access. The carriers forming one subchannel are not necessarily adjacent to each other. Each user may use part or all of the subchannels. The concept is illustrated in Figure 2.

The basic structure of a multi-carrier signal in the time domain is made up of time slots to support multiple-access. The resource division in both the frequency and time domains is depicted in Figure 3.

4.2 Detailed Description of Adaptive Transmission and Feedback

The underlying principle of adaptive transmission and feedback in a communication system is both to increase the degree of freedom and to supply side information in the

adaptation process such that the allocated modulation scheme, coding rates, pilot patterns, power levels, spatial processing schemes, subchannel configurations, etc. can be adjusted in accordance to the transmission channel states, thereby improving system performance or capacity.

We use AMCTP (adaptive modulation, coding, training and power control) as a general term hereafter where its variations can be applied to appropriate applications.

Figure 4 illustrates the control process between Device A and Device B during adaptive transmission. Device A transmits the data and the associated control information to Device B based on the output of the adaptation process. Device B measures the channel conditions and feeds back the channel quality information (CQI).

Figure 5 illustrates the joint adaptation process at the transmitter of an OFDM system which controls the coding, modulation, training pilot pattern, and transmission power for one subchannel. Figure 6 is an illustration of the control messaging associated with the data transmission between the communication devices: AMCTP indicator associated with the data transmission on the forward link from the transmitter to the receiver, and CQI feedback on the return channel from the receiver to the transmitter.

In a system where AMCTP is used, the transmitter relies on CQI to select an appropriate AMCTP scheme for the transmission of the next packet, or the retransmission of a previously failed packet required in automatic repeat request (ARQ) process. The CQI is a function of one or more of the following: the received signal strength, the average SINR, the variance in time, frequency or space, the measured BER, frame error rate (FER), or mean square error (MSE). Channel conditions hereafter are referred to as one or more of the following for a user or a subchannel: signal level, noise level, interference level, SINR, fading channel characteristics (Doppler frequency, delay spread, etc.), or channel profile in time or frequency domain. The detector of the channel condition can be implemented at the transmitter, the receiver, or both.

The granularity of AMCTP schemes in a multi-carrier system can be per user, which may use one or multiple subchannels, or per subchannel, which may contain one or more subcarriers. Likewise, the granularity of CQI can be per user or per subchannel. Both AMCTP and CQI may change over time and may be different from one time slot to another.

MCS in AMCTP is referred to as the modulation and error correction coding schemes used in the system. By matching MCS to a specific channel condition (e.g., SINR level), a better throughput can be achieved. However, only adjusting MCS is sub-optimal since other factors such as training pilot patterns or subchannel compositions certainly have impacts on the system performance.

A pilot pattern includes the number of (training) pilot symbols, the location of these symbols in time/frequency/space, the amplitude and phase, and other attributes of these symbols. The pilot pattern requirement for robust channel estimation varies with the SINR of the channel and the channel profile. The system may use distinctive pilot patterns for different MCS and channel conditions. The jointed adaptation of training pilot pattern together with MCS makes it more effectively matched to the channel condition thereby resulting in a better performance compared with that only adapts

MCS. One criterion for choosing a pilot pattern is such that the training pilots assisted channel estimation itself is not the bottleneck for the link performance whereas the pilot overhead is kept to the minimum level.

In a multi-carrier system, pilots are transmitted on certain positions in the time-frequency grid. For example, in Figure 7, two different pilot patterns are plotted for illustration purpose.

The power control information may include the requested absolute power level and/or the relative amount to increase or decrease the current power setting. In a multi-carrier system, the power levels of different subchannels are set differently such that minimum power is allocated to a subchannel to satisfy its required performance while minimizing interference to other users. The power control can be carried out on a per-user or per-subchannel basis. Figure 8 is an illustration of the power control in an OFDM system where digital variable gains G_1, G_2, ..., and G_N are applied to the subchannels which may use different modulations with different settings of transmission power levels. Variable gain of G_a in analog domain is used to control the total transmission power to meet the requirement of the transmission power of the device.

Table 1 is an example of the general AMCTP table (or CQI table). It should be noted that some pilot patterns in the table can be the same. The total number of index used to represent different combinations of the joint adaptation process can be different for AMCTP index and CQI index. For instance, it is not necessary to send the absolute transmission power information to the receiver(s). Some AMCTP info, such as relative power control info or code rate information, can be embedded in the data transmission instead of being conveyed in the AMCTP index.

Index	Modulation	Code Rate	Training Pilot	Transmit Power
1	QPSK	1/16	Pattern 1	Step size
2	QPSK	1/8	Pattern 2	Step size
3	QPSK	¼	Pattern 3	Step size
4	QPSK	½	Pattern 4	Step size
5	QPSK	½	Pattern 5	Step size
6	16QAM	½	Pattern 6	Step size
7	16QAM	½	Pattern 7	Step size
8	16QAM	¾	Pattern 8	Step size
9	16QAM	¾	Pattern 9	Step size

10	64QAM	2/3	Pattern 10	Step size
11	64QAM	5/6	Pattern 11	Step size
12	64QAM	5/6	Pattern 12	Step size
13	64QAM	5/6	Pattern 13	Step size
14	64QAM	5/6	Pattern 14	Step size

Table 1: An example of general AMCTP

In the general AMCTP table or CQI table, different training pilot patterns may be used for different modulations and code rates. However, even for the same modulation and coding, different patterns can be used to match different channel conditions. In order to make the table more efficient, more indexes can be allocated to the more frequently used scenarios, for example, several training pilot patterns can be allocated to the same MCS that is used more frequently to achieve finer granularity and thus have a better match to different channel conditions.

Table 2 is a simple realization of the AMCTP index or the CQI index. As shown in the table, in one embodiment, the AMCTP and CQI index is Gray coded.

Index (Gray coded)	Modulation	Code Rate	Training Pilot	Transmit Power
000	QPSK	¼	Pattern 1	Max
010	QPSK	½	Pattern 2	Max
011	QPSK	7/16	Pattern 3	Max
001	16QAM	½	Pattern 2	Max
101	16QAM	7/16	Pattern 3	Max
111	64QAM	2/3	Pattern 2	Max
110	64QAM	5/6	Pattern 3	Max
100	64QAM	5/6	Pattern 3	Max-X

Table 2: Another example of AMCTP or CQI table

In some cases, different number of pilot symbols is used for the same MCS. In one embodiment, in order to keep the packet size the same when the same MCS is used with different number of pilot symbols, rate matching scheme such as repetition or puncturing is used. For instance, in the above Table 2, for Index 010 and Index 011, Pattern 3 has more pilot symbols compared to Pattern 2. The code rate of Index 010 is ½, which is punctured to 7/16 for Index 011 to accommodate the extra pilot symbols.

In another embodiment, more important bits in the CQI index are protected with stronger error protection code on the return channel.

There are different adaptive transmission schemes that are subsets of the AMCTP scheme, such as AMCT (adaptive modulation, coding and training), AMTP (adaptive modulation, training, and power control), or AMT (adaptive modulation and training).

Other factors that can be used in the adaptation process include modulation constellation arrangement, transmitter antenna techniques, and subchannel configuration in a multi-carrier system.

For some modulation schemes such as 16QAM and 64QAM, how information bits are mapped to a symbol determines their reliability. In one embodiment, constellation arrangement is adjusted in the adaptation process to achieve a better system performance, especially during retransmission during a hybrid ARQ process.

Some multiple antenna techniques such as transmission diversity are used to improve the transmission robustness against fading channel effects, whereas other multiple antenna techniques such as multiple-input multiple-output (MIMO) scheme are used to improve transmission throughput in favorable channel conditions. In one embodiment of the adaptive transmission, which antenna technique to use for a transmission is determined by the adaptation process.

In a multi-carrier multi-cell communication system, when all subcarriers in one subchannel are adjacent or close to each other, they are more likely to fall in the coherent bandwidth of a fading channel; thus they can be allocated to users that are either fixed in location or are moving slowly. On the other hand, when subcarriers and/or subchannels that belong to one user are scattered in the frequency domain, it has higher diversity gains for fast moving users, and also has better interference averaging effect. Given the fact that different configurations of subchannel compositions are suitable for different scenarios or user profiles, in one embodiment, it is included in the transmission adaptation process. In one embodiment, the subchannel configuration information is broadcast on the common forward control channel to all users such that each user is informed of its subchannel configuration.

In another embodiment, the subchannel configuration can be adjusted according to deployment scenarios. For instance, when a base station is newly deployed with less interference, one form of subchannel configuration is used; when more users join the network or more adjacent base stations are deployed which results in stronger interference to the users in the system, a different subchannel configuration with better interference averaging effect is used.

In what is followed, we describe the method of how to transmit the control message between the transmitter and the receiver when AMCTP scheme is implemented. The

forward control link is defined as the transmission of the AMCTP indictor from the transmitter to the receiver, whereas the return control channel is defined as the transmission of CQI as the feedback information from the receiver to the transmitter, as shown in Figure 4.

The AMCTP indicator on the forward link can be sent either separately or jointly. For instance, the power control information, training pilot pattern indicator, or antenna diversity scheme can be embedded in the data transmission. In another embodiment, AMCTP is transmitted on a separate control channel with stronger error protection for its importance.

One means for the transmitter to obtain CQI is to have it explicitly sent from the receiver to the transmitter based on the measurement of the channel condition at the receiver during previous transmission(s). The CQI is then used by the transmitter at the adaptation process to determine which AMCTP scheme to use for the next transmission. In one embodiment, CQI is periodically updated on the return channel even when there is no consecutive data transmission targeted for the user. In this case, the receiver measures the channel condition from the common broadcast transmission or the data transmission targeted to other users.

In one embodiment, the transmitter or the receiver uses predictive algorithm to predict current or future channel conditions based on previous channel measurements. This is especially effective for fast fading environment where the past measurements may not match closely to the current transmission due to the fast variation of the channel. The output of the predictive algorithm is then used by the adaptation process to select the best possible scheme for the current or future transmission.

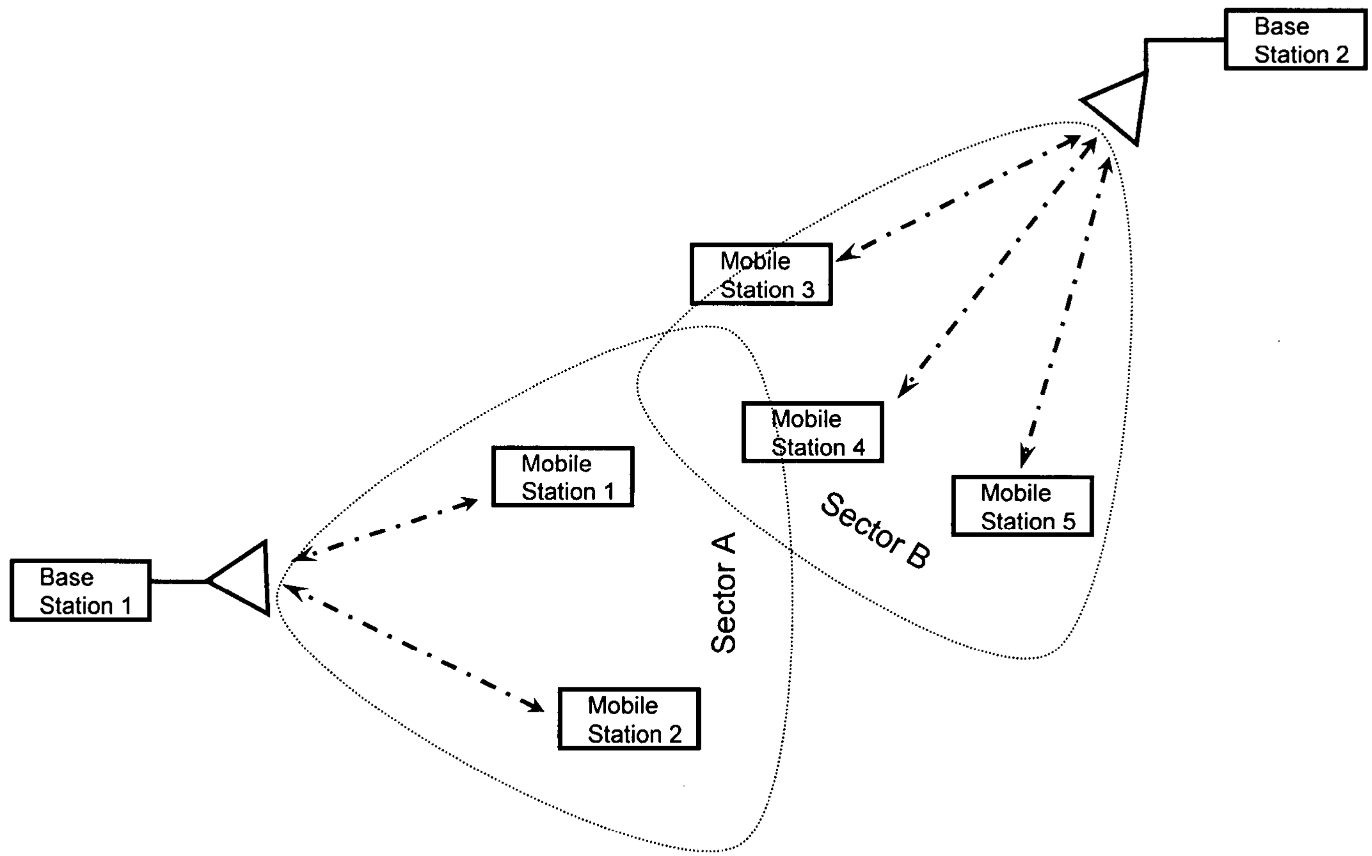
Another method to obtain CQI is through the transmission of a probing sequence from the receiver to the transmitter. In one embodiment, in a multi-carrier communication system, a probing sequence is transmitted from the receiver to the transmitter using an overlay scheme where a probing sequence is overlaid to the data traffic without having negative impact on the data transmission performance. In this case, the transmitter estimates the channel profile in the time and/or frequency domains based on the received probing sequence. This is especially effective for a TDD system due to the reciprocity of the channel conditions on its forward and reverse channels.

The AMCTP indicator or CQI can be sent per user or per subchannel. If per subchannel feedback is used, since the AMCTP and CQI information for the same users is highly correlated, in one embodiment, source coding is first used to compress the CQI, and error correction coding is then applied to the compressed CQI to provide sufficient error protection.

In one embodiment in hybrid ARQ retransmission, the transmitter may not use the requested CQI for the retransmission as it may use for a new packet transmission; instead, it selects an AMCTP scheme that is appropriate for the retransmission in order to reduce interference to other users.

It should be pointed out that the AMCTP index used for the transmission from the transmitter to the receiver may be different from the CQI that the receiver requested,

since the transmitter may have other considerations such as quality of service (QoS) for different users, network traffic load, and power allocation limit.



Base Station 2
Mobile Station 3
Mobile Station 4
Mobile Station 5
Mobile Station 1
Sector A
Sector B
Base Station 1
Mobile Station 2

Figure 1

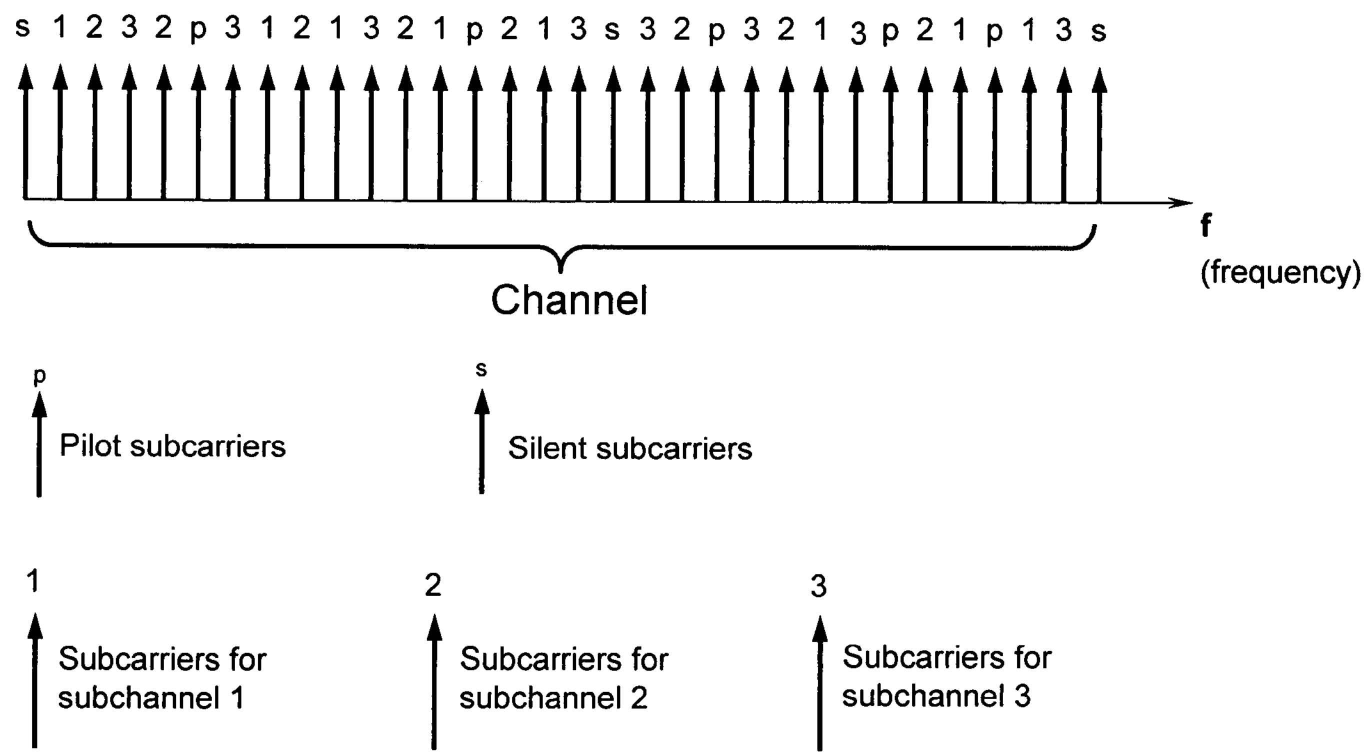

s 1 2 3 2 p 3 1 2 1 3 2 1 p 2 1 3 s 3 2 p 3 2 1 3 p 2 1 p 1 3 s
f
(frequency)
Channel
p
Pilot subcarriers
s
Silent subcarriers
1
Subcarriers for subchannel 1
2
Subcarriers for subchannel 2
3
Subcarriers for subchannel 3

Figure 2

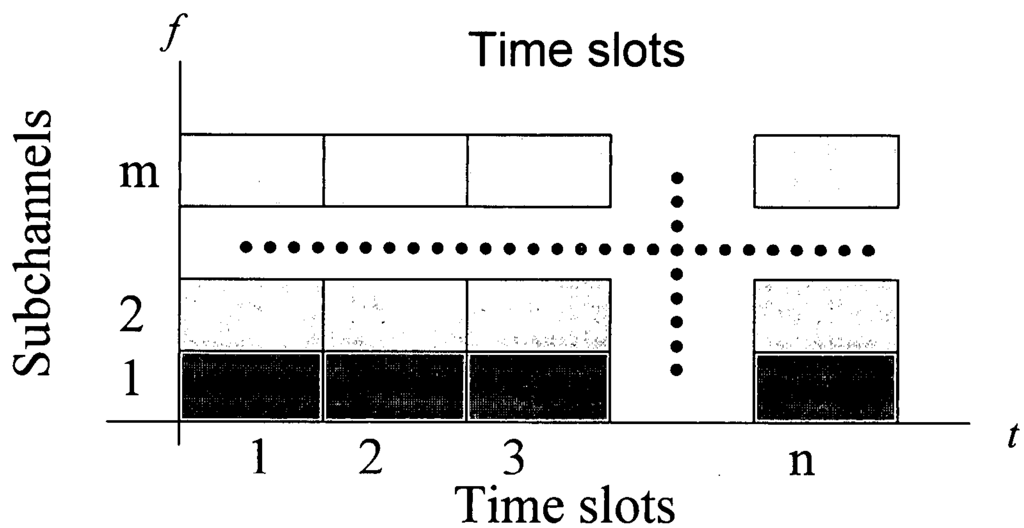
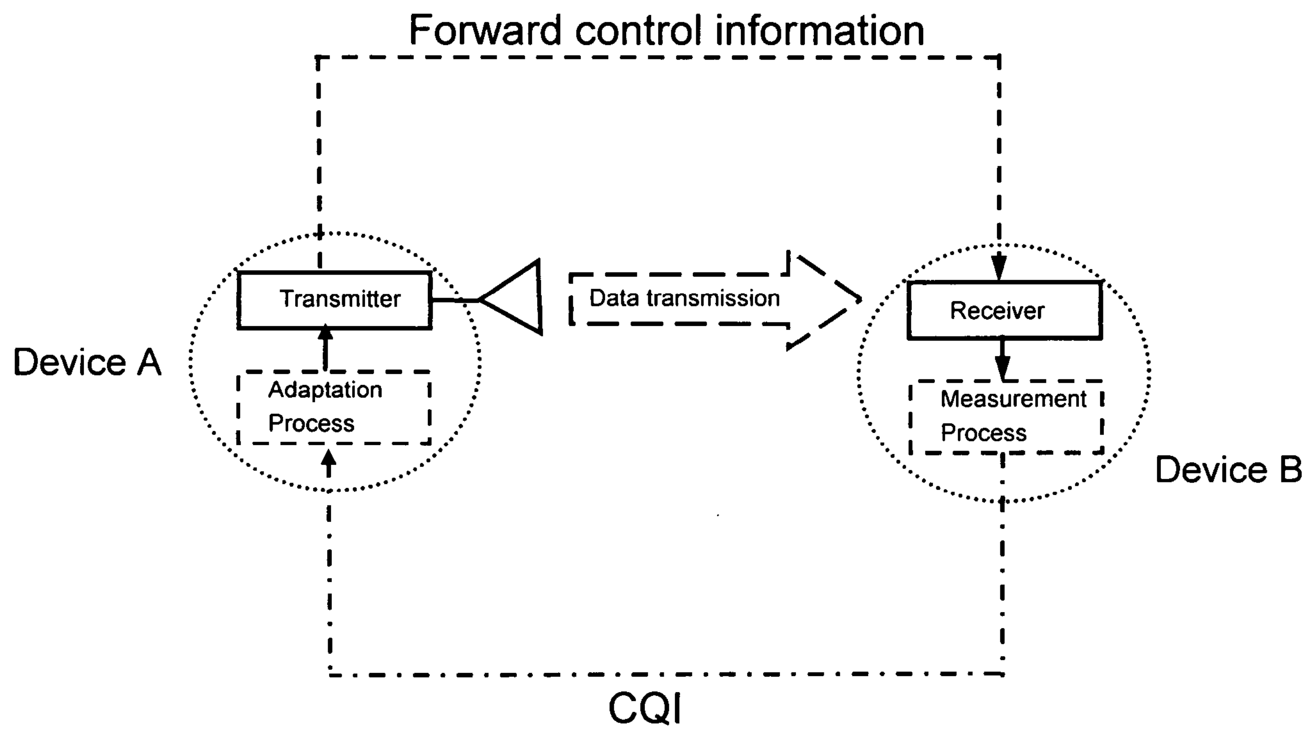


Figure 3



Forward control information
Device A
Transmitter
Adaptation Process
Data transmission
Receiver
Measurement Process
Device B
CQI

Figure 4

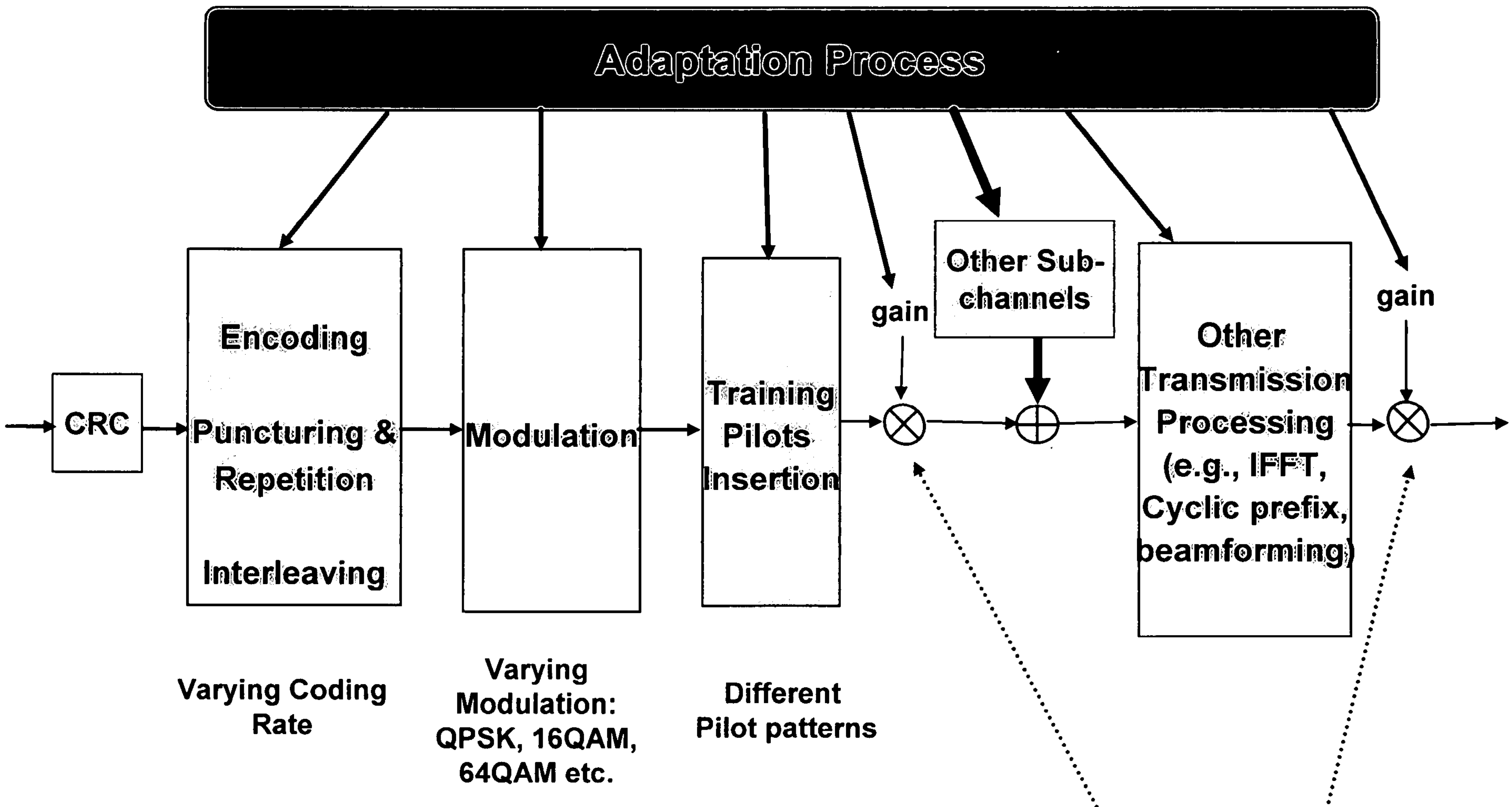

Adaptation Process
CRC
Encoding
Puncturing &
Repetition
Interleaving
Modulation
Training
Pilots
Insertion
gain
Other Sub-
channels
Other
Transmission
Processing
(e.g., IFFT,
Cyclic prefix,
beamforming)
gain
Varying Coding
Rate
Varying
Modulation:
QPSK, 16QAM,
64QAM etc.
Different
Pilot patterns
Transmission
Power Control

Figure 5

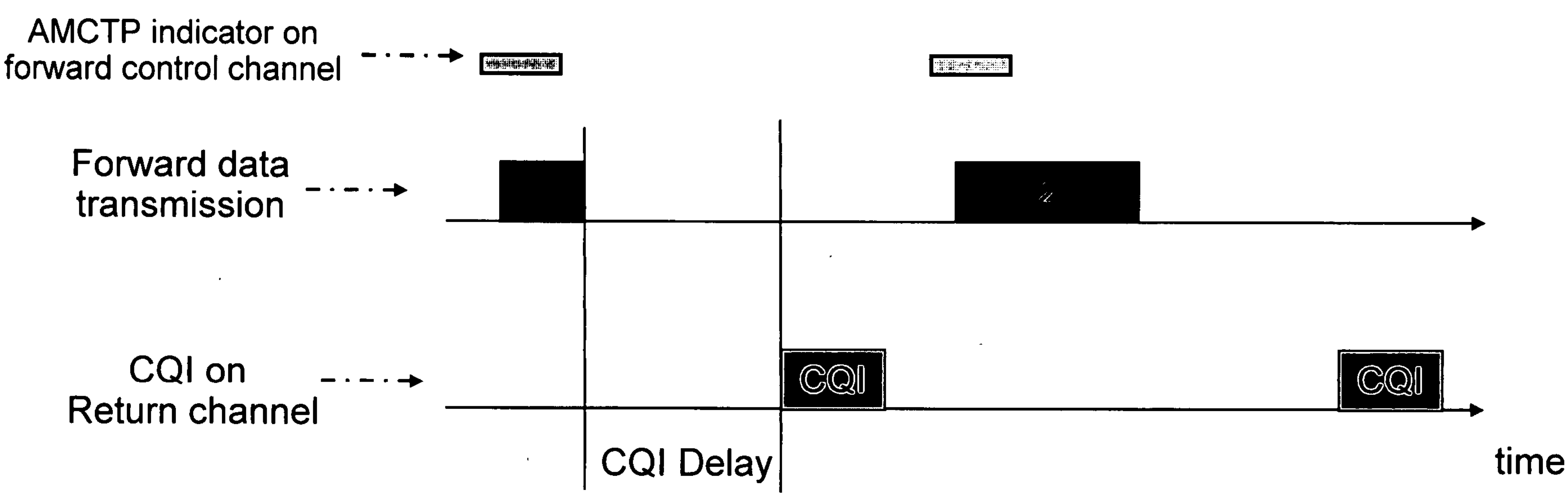
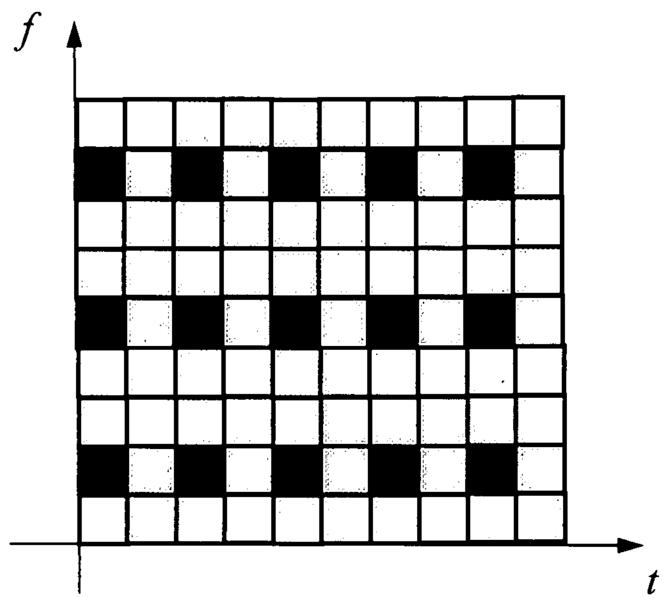
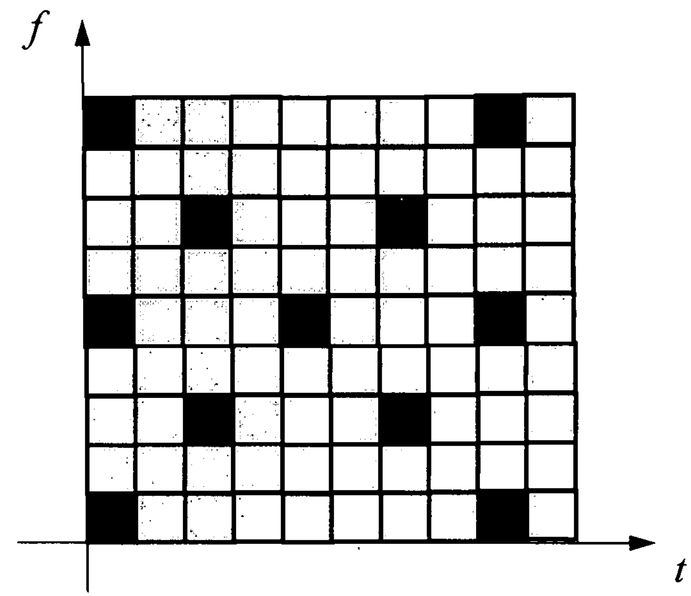

AMCTP indicator on
forward control channel
Forward data
transmission
CQI on
Return channel
CQI
CQI
CQI Delay
time

Figure 6

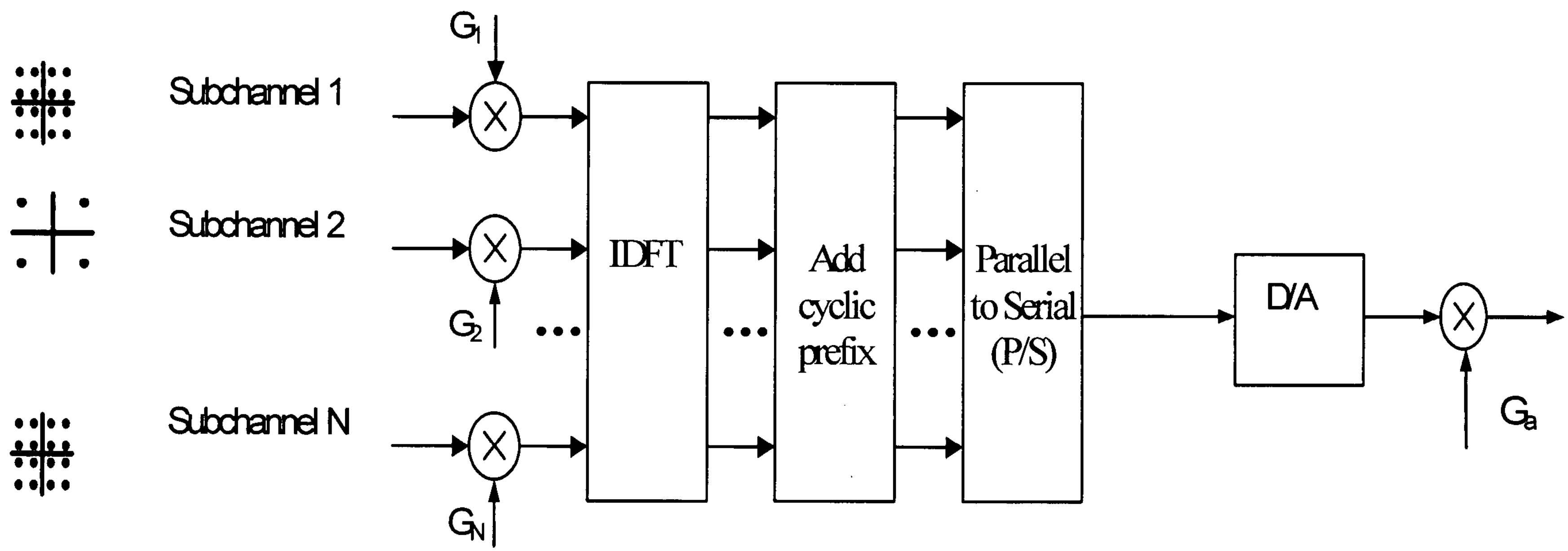


4.a



4.b

Figure 7



G1
Subchannel 1
Subchannel 2
G2
Subchannel N
GN
IDFT
Add cyclic prefix
Parallel to Serial (P/S)
D/A
Ga

Figure 8